Ocean Remote Sensing Using Ambient Noise

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LONG-TERM GOAL

Our long-term scientific goal is to understand the basic physics of low-frequency sound propagation in the ocean, and the effects of environmental variability on signal stability and coherence. We seek to understand the fundamental limits to signal processing imposed by ocean variability to enable advanced signal processing techniques, including matched field processing and other adaptive array processing methods.

OBJECTIVES

Work on this project has focused on noise interferometry – the process by which an approximation to the transient Green's function $G(x_A|x_B, t)$ between locations x_A and x_B is estimated by cross-correlating records of ambient noise measured at x_A and x_B. In that context, our objective is to investigate and identify the limitations of noise interferometry for remote sensing applications in a variety of ocean environments.

APPROACH

The objective stated above objective has been addressed using a combination of field experiments, theoretical investigations, simulations, and signal processing algorithm development. The stated objective is broad and geographically unconstrained. With this in mind, coupled with realistic fiscal constraints associated with the cost of doing ocean acoustic field work, our approach has been to perform field work in the Straits of Florida, the logistics of which is very simple. That field work has been partially supported by NSF. Field work has been complemented by data-driven theoretical investigations, simulations and signal processing algorithm development.

WORK COMPLETED

The work listed below is in various stages of completion. The work listed in items 1, 2, 3 and 4 is complete. The work described in items 5 and 6 is ongoing.

1. Demonstration of noise interferometry at 10 km range in a shallow water environment

Recently conducted experiments in the Florida Straits at 100 m and 600 m depth demonstrate the utility of noise interferometry at 5 and 10 km range. Preliminary results for the experiment at 100 m depth are described by Brown et al. (2014). Stable cross-correlation functions are shown to require coherent stacking over a period of about 1.5 day for point measurements. Both ray- and mode-based simulations are shown to be in approximate agreement with measured cross-correlation functions.

2. Estimation of depth-averaged currents using noise-interferometric data

Two-point cross-correlation functions derived from noise interferometry contain information, at positive and negative lags, about propagation between sensors in opposite directions. Thus, there is information in the two-point cross-correlation functions about non-recriprocal propagation effects. In particular, currents can be estimated from such data. The utility of estimating depth-averaged currents between sensors using noise-interferometric data collected in the Florida Straits is demonstrated in Godin et al. (2014). The noise-interferometry-based estimate of the depth-averaged current is shown to be consistent with ship-based current measurements.

3. Waveform modeling and inversion of noise-interferometric data

Two-point noise-interferometric cross-correlation functions contain much finestructure that contains information about the environment. In order to make use of wave-equation-based modeling of correlation functions and exploit the information contained in cross-correlation function waveforms in an inverse analysis, one must understand and account for small differences between cross-correlation functions and Green's functions. Zang et al. (2015) discuss those differences and use that knowledge to perform a waveform inversion of a two-point cross-correlation function measured in the Florida Straits.

4. Green's function retrieval in a field of random water waves

To better understand random wave interferometry in a broader context, random water wave interferometry was studied. Results are described in Brown and Lu (2015): the theory of water wave interferometry is developed; simulations and wavetank measurements are shown to be in good agreement with theoretical predictions; field measurements are not in agreement with theoretical predictions, however, for reasons that are described.

5. Time-reversal processing and inversion of noise-interferometric data

It is now well established that the response measured at one or more receivers to a transient point source can be time-reversed and back-propagated to form a spatio-temporal focus at the original source location. The technique works best in strongly multipathing environments and/or when

multiple receivers are used. We have demonstrated (Godin et al., 2015) the feasibility of time-reversal/back-propagation using two-point noise-interferometric cross-correlation functions measured in the Straits of Florida.

6. Extraction of dispersion curves from noise-interferometric data using time-warping

Time-warping is a nonlinear signal processing technique that allows contributions from modal pulses corresponding to different mode numbers to be isolated, even when there is significant overlap in time between modal pulses. (A modal pulse is a broadband distribution of energy with a fixed mode number.) In a near-ideal shallow water waveguide the time-warping transformation is well-known, and has previously been shown to be robust. We have demonstrated (Brown et al., 2015) that when applied to two-point noise-interferometric cross-correlation functions measured in the Straits of Florida, the time-warping transformation successfully isolates the first four modal pulses, and that the associated dispersion curves are in good agreement with the previously performed inverse analysis described in Zang et al. (2015).

RESULTS

Our relatively recent interest in, and work on, noise interferometry is beginning to bear fruit. We have successfully demonstrated the feasibility of noise interferometry at ranges of 5 and 10 km in water depths of 100 m and 600 m. (Previous demonstrations were at much shorter ranges.) We have demonstrated the feasibility of estimating ocean currents using noise interferometry. We have quantified differences between correlation functions and Green's functions, and we have used this knowledge to perform a waveform inversion of a measured noise-interferometric two-point cross-correlation function. Using noise-interferometric two-point cross correlation functions we have demonstrated the feasibility of exploiting time-reversal/back-propagation techniques to produce a back-propagation focus. Also we have demonstrated, using the same data, the feasibility of using time-warping techniques to isolate overlapping modal pulses and estimate modal dispersion curves.

IMPACT/APPLICATION

Our work is contributing to an improved understanding of the basic physics of low-frequency sound propagation in the ocean, and the associated loss of signal stability and coherence imposed by environmental variability. This knowledge contributes to an understanding of the limitations of advanced signal processing techniques, such as matched field processing.

TRANSITIONS

We are unaware of transitions to system applications, but a potential application is obvious: our results build the foundation for developing a purely passive ocean remote sensing system.

RELATED PROJECTS

The PI's principal collaborators are O. Godin at ESRL/UColorado; I. Udovydchenkov at MITRE (formerly at WHOI), R. Andrew and B. Dushaw at APL/UW; P. Worcester, W. Munk, B. Cornuelle, and M. Dzieciuch at SIO; B. Howe at UHawaii; and J. Colosi at NPS.

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PUBLICATIONS

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